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International Conf. on Computational Engineering & Science **(Statement A)**
(Puerto Vallarta, Mexico, 24-28 August 2001) (Deadline: 15 June 2001)

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Hybrid Experimental-Numerical J-Integral Analysis and Crack Growth Resistance of a Particulate Composite Material

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Abstract

In this study, a hybrid experimental-numerical method was used to determine the J-integral value in a particulate composite material subjected to a constant strain rate condition. The experimental data were analyzed and the results are discussed.

Introduction

An important engineering problem in structural design is evaluating structural integrity and reliability. It is well known that the strength may be degraded by the presence of cracks in the material. In order to determine the severity of the crack or the ultimate service life of the structure, the failure criterion should include the crack propagation aspect of the localized failure. In order to achieve this goal, the effects of crack sizes and the rate of growth on the fracture resistance of the material need to be investigated.

Crack propagation in particulate composite materials, containing hard particles embedded in rubber matrix, has been an important subject of research for many years (1-4). The basic approach used in characterizing crack growth behavior of these materials is based on linearly elastic or linearly viscoelastic fracture mechanics. Experimental results reveal that a power law relationship exists between the crack growth rate and the Mode I stress intensity factor. This experimental finding supports the linear viscoelastic fracture mechanics theories developed by Knauss (~~5~~ 6) and Schapery (~~6~~ 5).

In this sentence, you might want to list "Schapery (5)" first, then "Knauss (6)" to keep references in order.

In this study, edge-cracked sheet specimens (Fig.1) were used to investigate the crack growth behavior in a particulate composite under a constant strain rate (0.067 min^{-1}) at room temperature. The specimens were made of a highly filled polymeric material, containing hard particles in a rubbery matrix. A 12.7 mm crack was cut at the edge of the specimen with a razor blade. A hybrid method, consisting of experimental and numerical analyses, was used to determine the J-integral as a function of the applied strain. The experimental data were analyzed and the results are discussed.

The experiments

In this study, California Institute of Technology's testing equipment was used to conduct the constant strain tests. It includes a straining stage driven by a stepping motor through a flexible cable, a Nikon microscope, a CCD camera, and a personal computer with a frame grabber unit. The straining stage is mounted on a positioning stage, for which a joy-stick controller allows the positioning of the straining stage under the Nikon microscope. A detailed description of the testing equipment can be found in Ref. 7. Add a space here

During the test, two light sources were used and their positions were chosen carefully to minimize the shadows on the specimen surface. The deformation process was monitored with a 200 mm zoom lens that attached to a CCD camera, which captured an area of 24 mm by 18 mm on the specimen surface. The images of the specimen surface were stored at a rate of one image per five seconds and they were used to determine the strain fields near the crack tip.

Data analysis

In this study, digital image correlation techniques, developed by Sutton and his colleagues (8) and improved by Vendroux and Knauss (9), were used to measure the displacement fields and their gradients from images of undeformed and deformed states. his" These information, together with a Ramberg-Osgood constitutive law, ~~were~~ was used to calculate the strain, stress, energy density, and J-integral values for a given applied strain.

A J-integral computer program was written and incorporated in a finite element computer code (FEAP). The accuracy of the J-integral program was checked by calculating the J-integral for a given HRR fields associated with a known J-integral value. The result indicates that the calculated and the prescribed J-integral values differ by 3%. The path – independent nature of the J-integral was checked by computing the J-integral values along 9 different rectangular paths. The closest path to the crack tip was 1.9 mm from the crack tip whereas the farthest one was 5.3 mm from the crack tip. The results indicate that the variation of the computed J-integral values along different paths is within 1%.

In order to check the accuracy of the digital image correlation technique, a specimen of homogeneous silicone rubber without a crack and coated with microscopic speckles was stretched sequentially and uniaxially to a maximum strain of 70% in a sequence of 12 deformation steps of 5.08% strain each. These strains were recorded (optically) with the aid of a microscope by keeping track of the special marks (equal to prescribed strain). In addition, the digital image correlation program was used to compute the strain at a given deformation step. A comparison of the prescribed strain, obtained optically, and the computed strain, obtained by digital image correlation technique, revealed that a maximum deviation of 1% occurs at a strain of 40%. This precision is considered to be acceptable for experimental mechanics investigations.

Results and Discussion

A plot of J-integral values as a function of the applied strain is shown in Fig.2. It is noted that the rate of change of the J-integral value per unit of the applied strain level increases significantly when the applied strain level is high. Experimental results reveal that the J-integral values vary among the 9 paths, and the variation increases with increasing applied strain. However, the variation is small, especially when the applied strain level is low. A plot of the standard deviation of the J-integral values among the 9 paths as a function of the applied strain is shown in Fig. 3. It is seen that the standard deviation increases with increasing applied strain levels, and at higher applied strain levels the standard deviations fluctuate. It is believe that this phenomenon is due to the microstructure effect and damage developed in the material under higher applied strain levels. Based on these experimental findings, on the first approximation, it can be assumed that the J-integral is independent of path.

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The crack growth resistance curve, plotted the J-integral value versus the crack growth increment, is shown in Fig. 4. It is noted that a considerable amount of stable crack growth takes place before the unstable crack growth occurs. The J-integral value corresponding to the unstable crack growth is 3 times higher than that corresponding to the onset of crack growth. A plot of crack growth rate versus J-integral value is shown in Fig.5. According to Fig. 5, a power law relationship exists between the crack growth rate and the J-integral. Mathematically, it can be represented as

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$$da/dt = C\,J^{B}$$

where C and B are constants.

Conclusion

In this study, a hybrid experimental-numerical method was used to determine the J-integral value of a particulate composite material. Experimental findings reveal that the local J-integral value along a given path of integration fluctuated due to the nonhomogeneous of the microstructure and the fluctuations along different path of integrations vary. However, the variations of the accumulated or the final J-integral values among the ten different paths are small. Therefore, on the first approximation, it can be assumed that the J-integral value is independent of the path of integration. In addition, a considerable amount stable crack growth takes place in this material and a power relationship exists between the crack growth rate and the J-integral.

"of"

either use "nonhomogeneous nature" or "nonhomogeneity"

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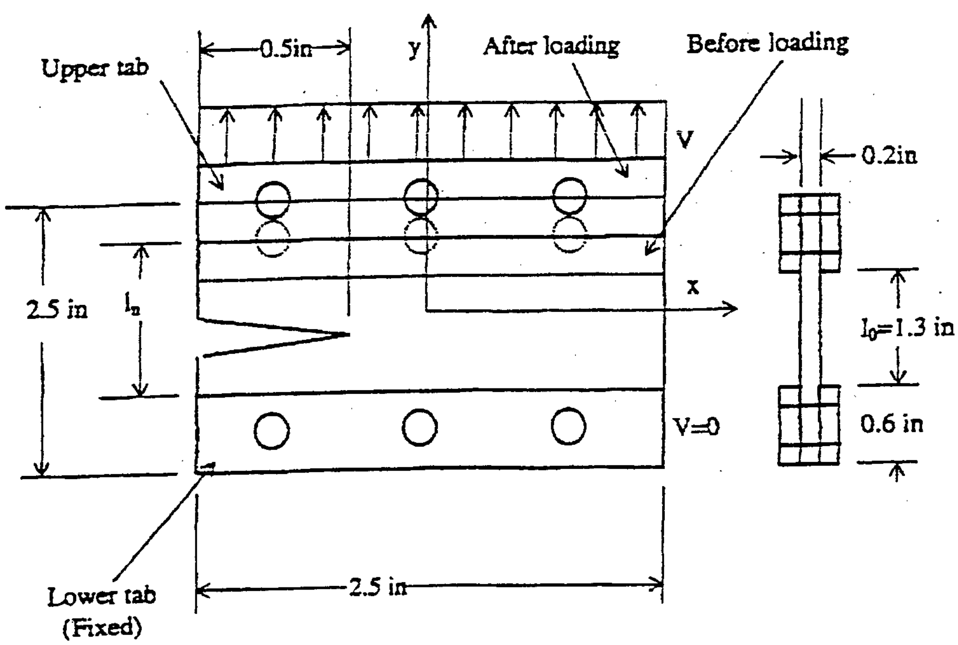

Fig. 1 Specimen geometry.

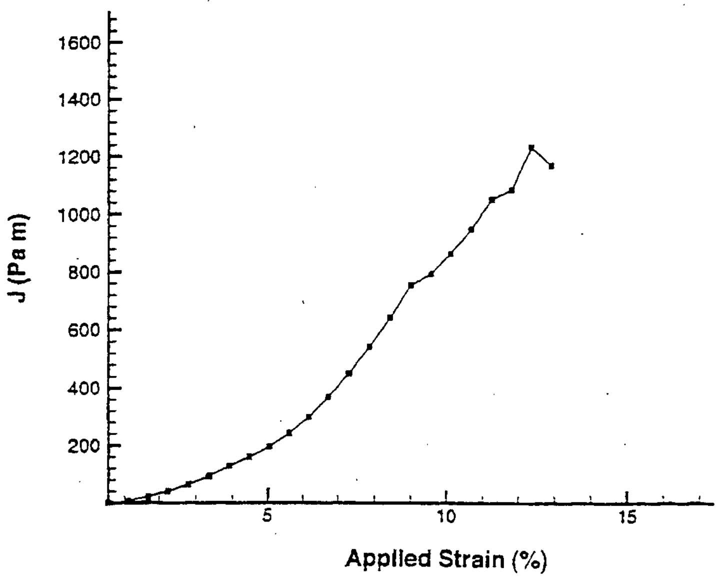

Fig. 2 J-integral versus applied strain.

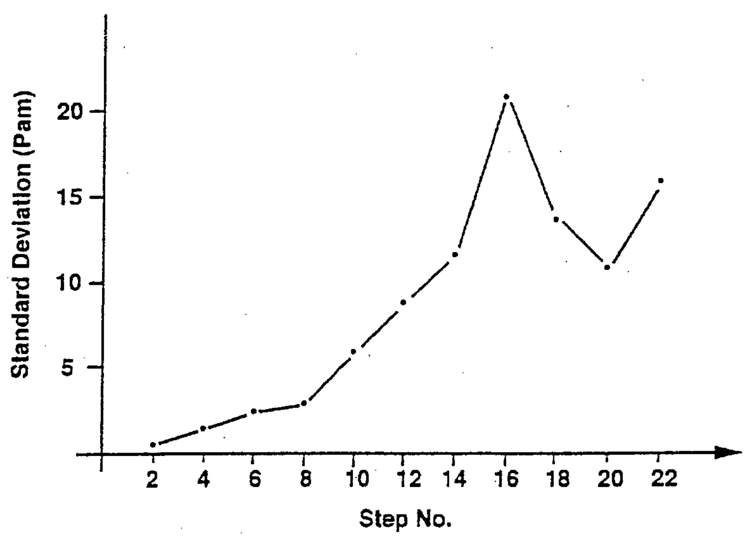

Fig. 3 Standard deviations of J-integral versus step numbers.
(1 step = 0.56% strain)

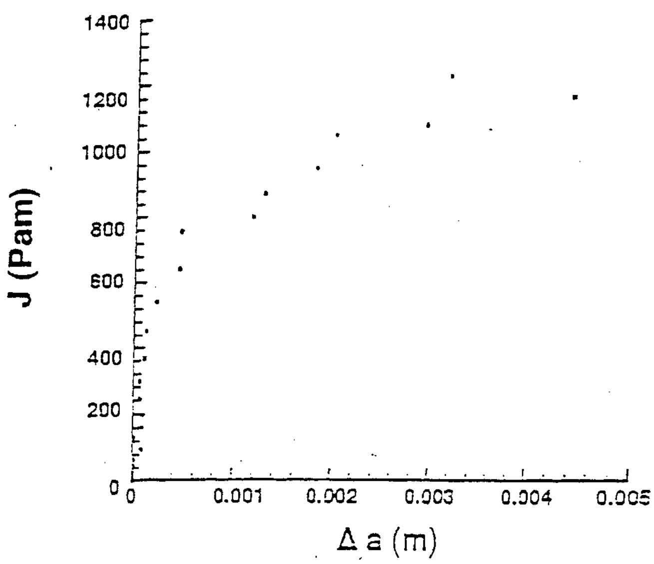

Fig. 4 Crack growth resistance curve.

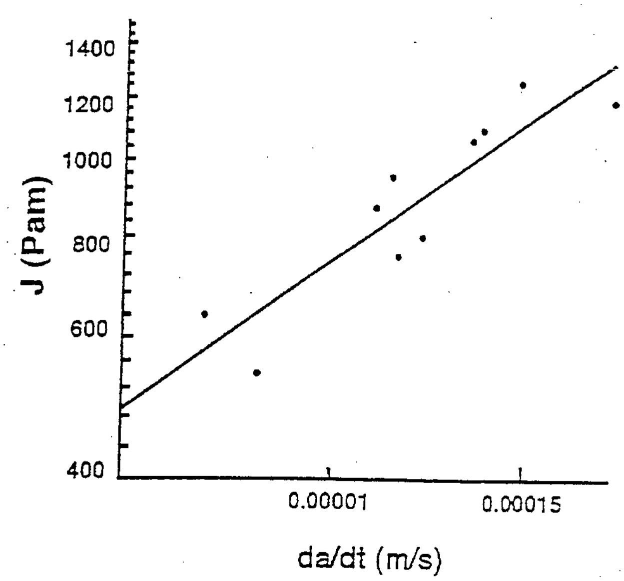

Fig. 5 Crack growth rate versus J-integral.